



Optimized Quads for Collider IP

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MCTF Thursday

5/28/09

- Motivation
- Super-conductor properties
- Cos theta quadrupole optimization
- Aside on "block" design
- Grading super-conductor current density (p9)
- Use of exotic magnetic materials
- Application to Collider final focus
- Open mid-plane dipole
- New Collider Parameters
- Conclusion

Motivation

Luminosity

$$\mathcal{L} = n_{\text{turns}} f_{\text{bunch}} \frac{N_\mu^2}{4\pi\sigma_\perp^2}$$

$$\mathcal{L} \propto \frac{\langle B \rangle P_{\text{beam}} N}{\epsilon_\perp \beta^*}$$

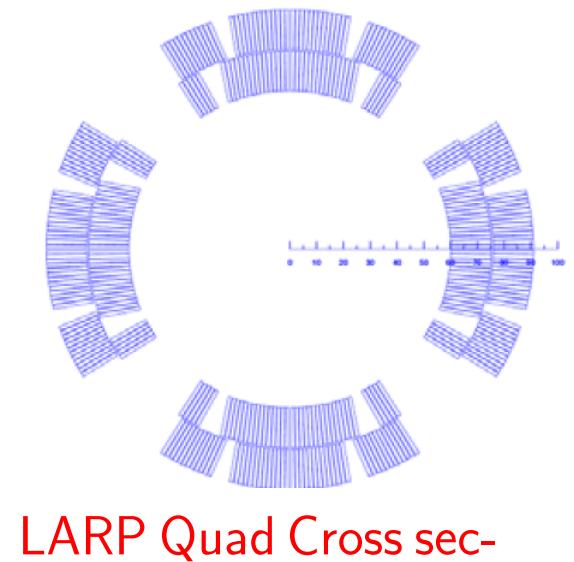
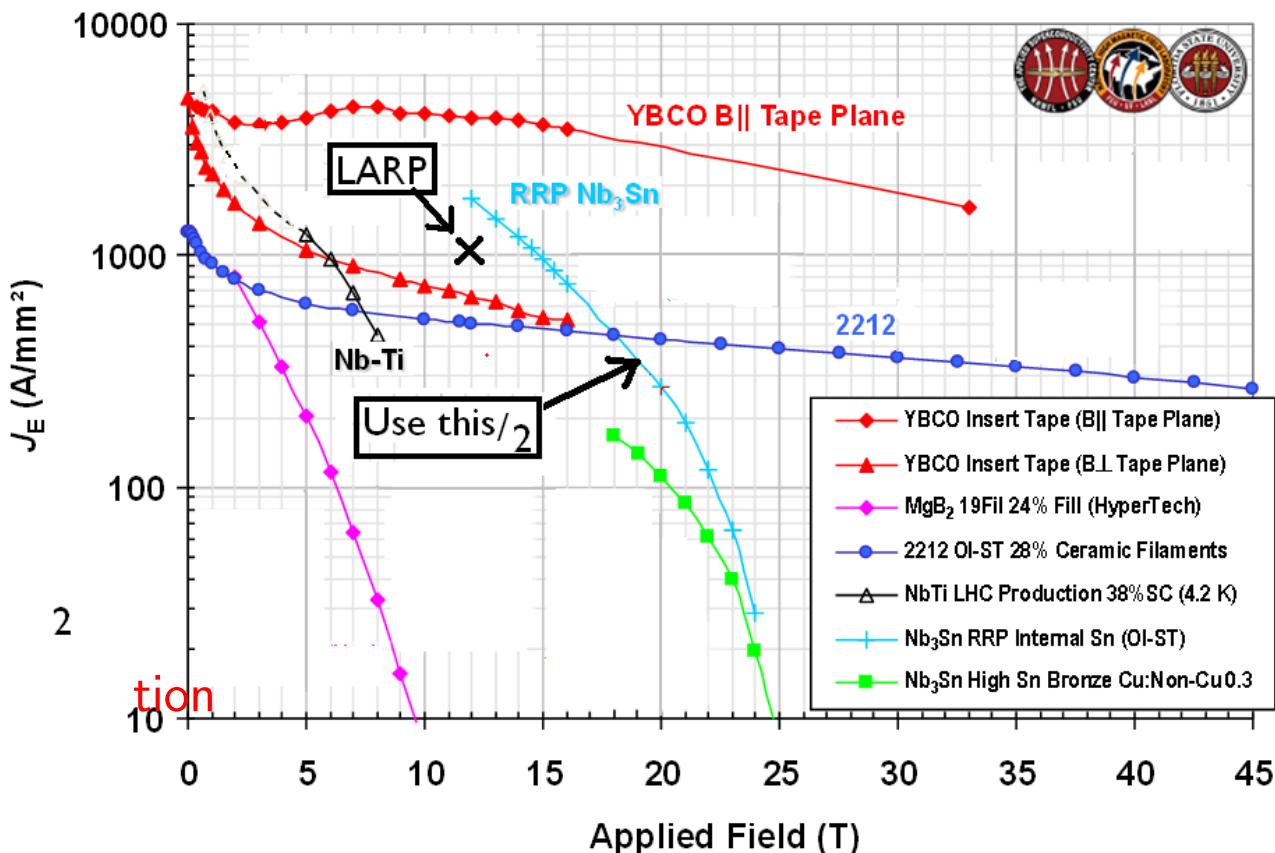
- We may have trouble getting $N = 2 \cdot 10^{12}$
 - We may have trouble getting $\epsilon = 25 \cdot 10^{-6} \text{ m}$
 - We may have trouble getting 7% cooling transmission
 - Beam beam tune shift $\Delta\nu$ may not be a constraint
-
- Look for other ways to recover Luminosity
 - More proton power (Chuck)
 - Higher $\langle B \rangle$ <<<<<<
 - Lower β^* <<<<<

Advances in SC Quadrupole Design

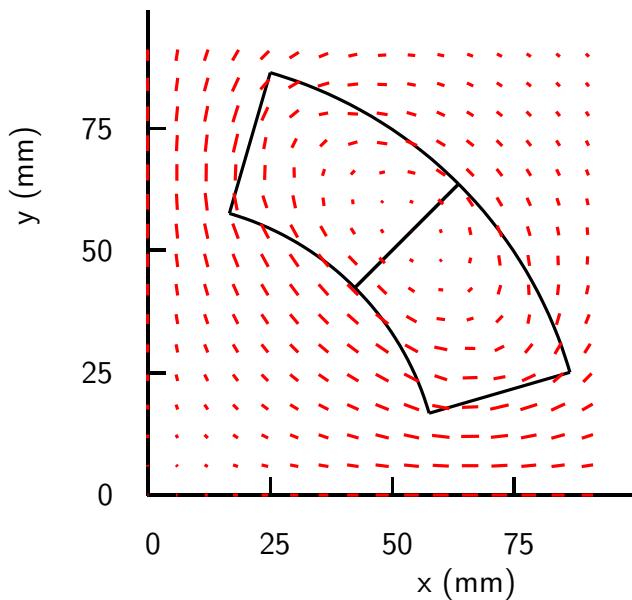
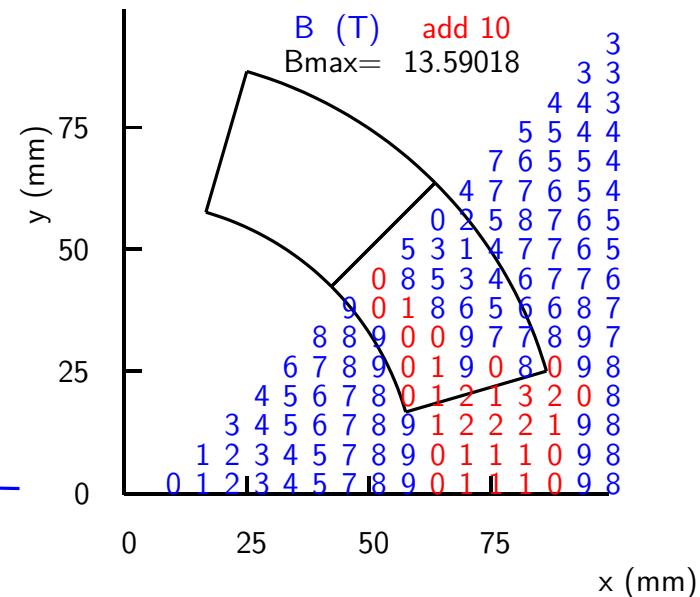
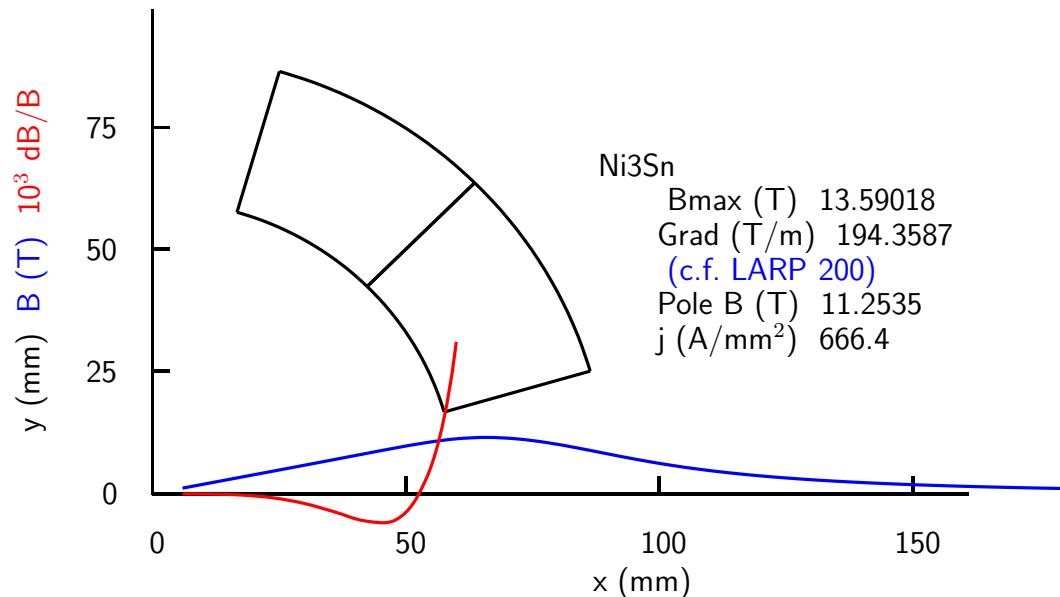
Design of HQ – a High Field Large Bore Nb₃Sn Quadrupole Magnet for LARP

H. Felice, G. Ambrosio, M. Anerella, R. Bossert, S. Caspi, D. Cheng, D. Dietderich, P. Ferracin, A. K. Ghosh, R. Hafalia, C. R. Hannaford, V. Kashikhin, J. Schmalze, S. Prestemon, G.L. Sabbi, P.Wanderer, A.V. Zlobin

Above magnet now under construction uses conductor performance:

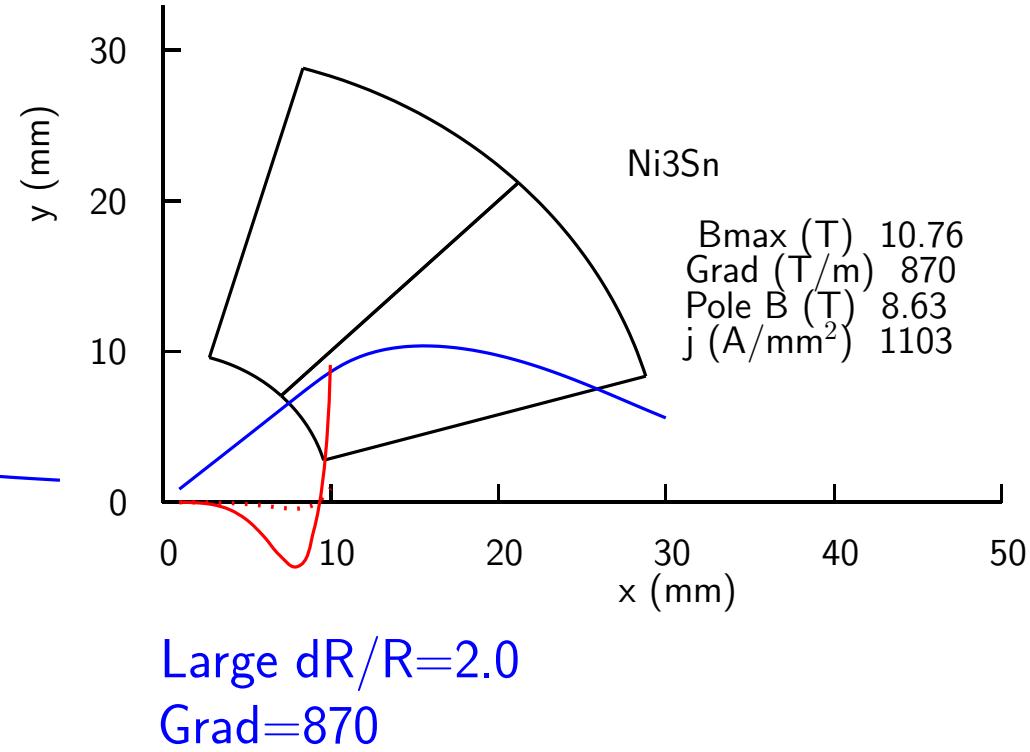
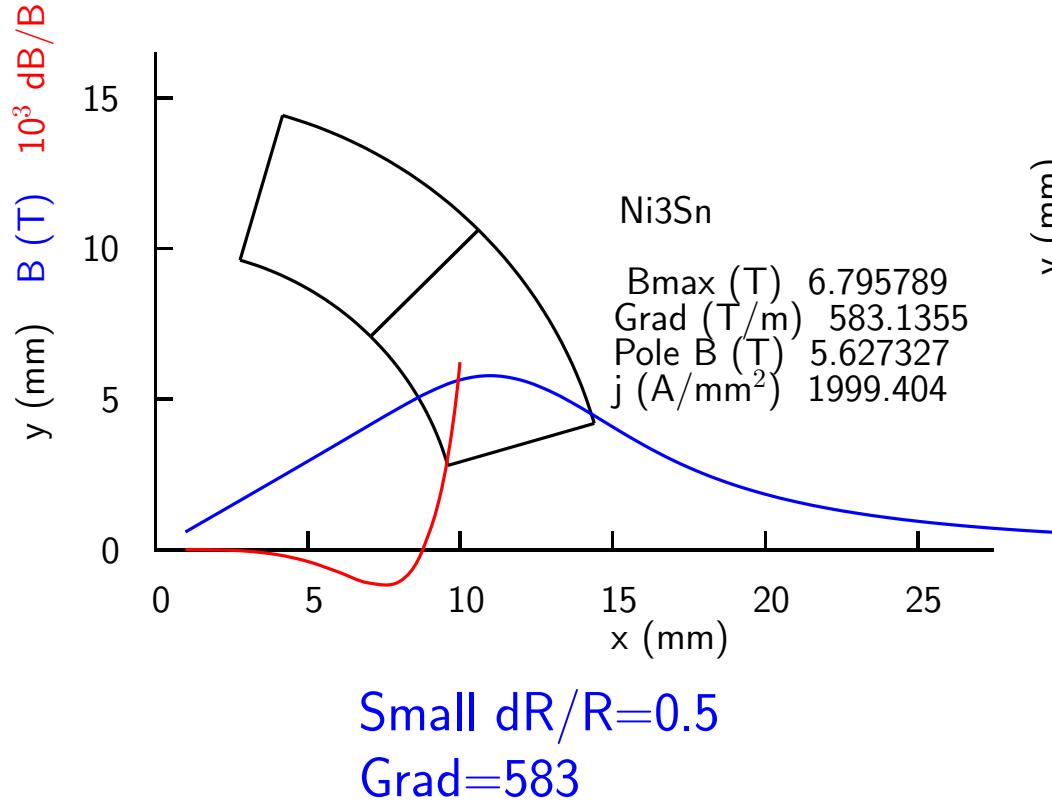


Reproduce LARP Design



- Gradient found of 194 T/m
c.f. LARP's 203 T/m
Good agreement
- Note field at all angles
- So YBCO is not suitable

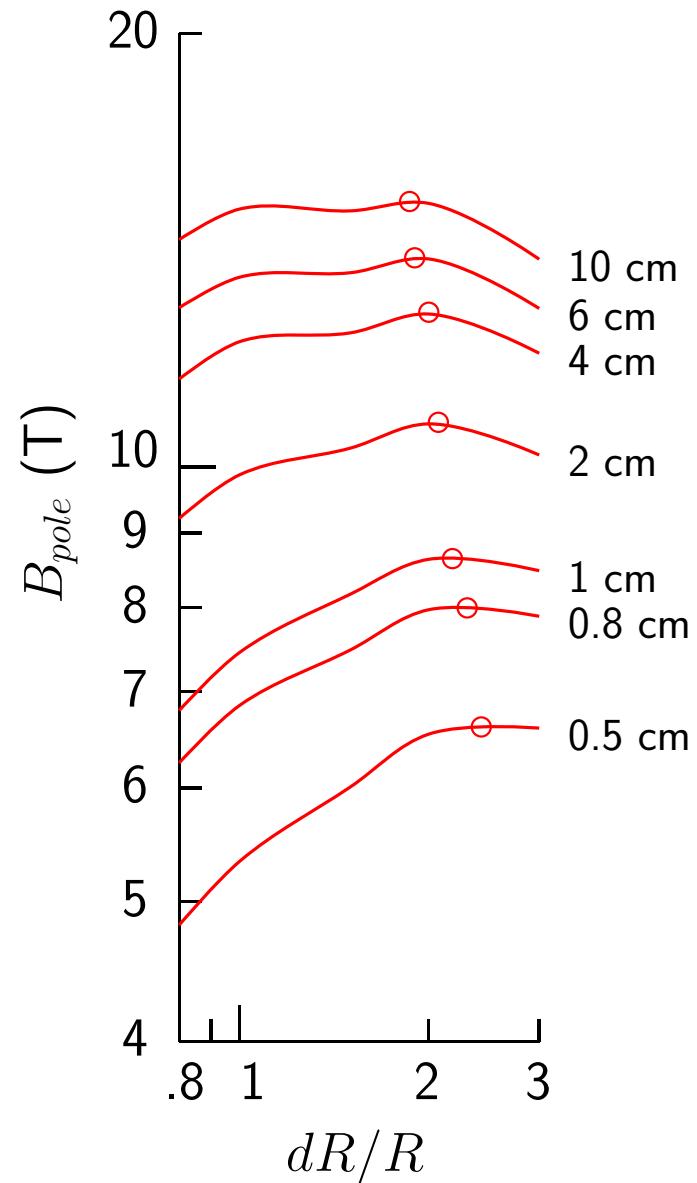
Scale R down to 1 cm



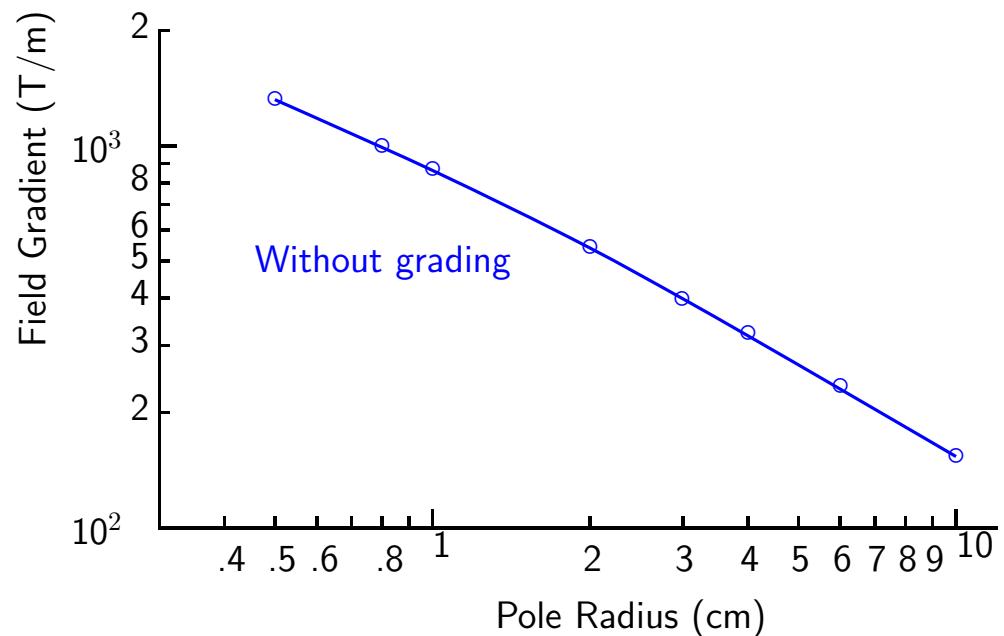
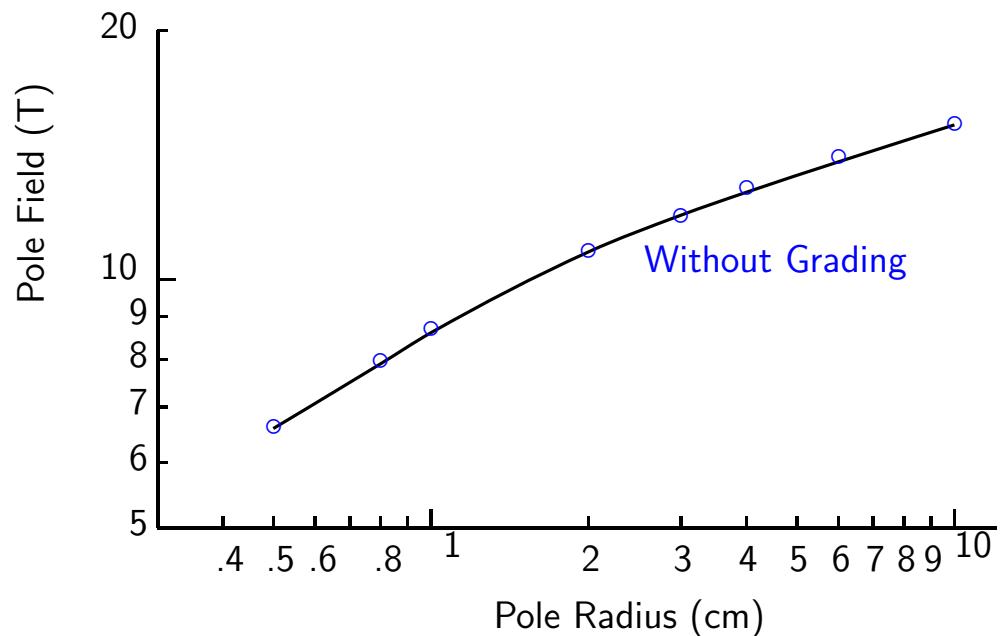
- Max fields higher in $dR/R=2.0$, current densities lower, but gradient still higher
- $dR/R=0.5$: Radial width of conductor (0.5 cm) much less than LARP (3 cm)
- $dR/R=2.0$: Radial width of conductor (2 cm) still less than LARP (3 cm) but key-stoning is more severe and will need R&D

Search for optimum dR/R for different R

- Optimum always near $dR/R = 2$
- But Large dR/R more useful at low radii

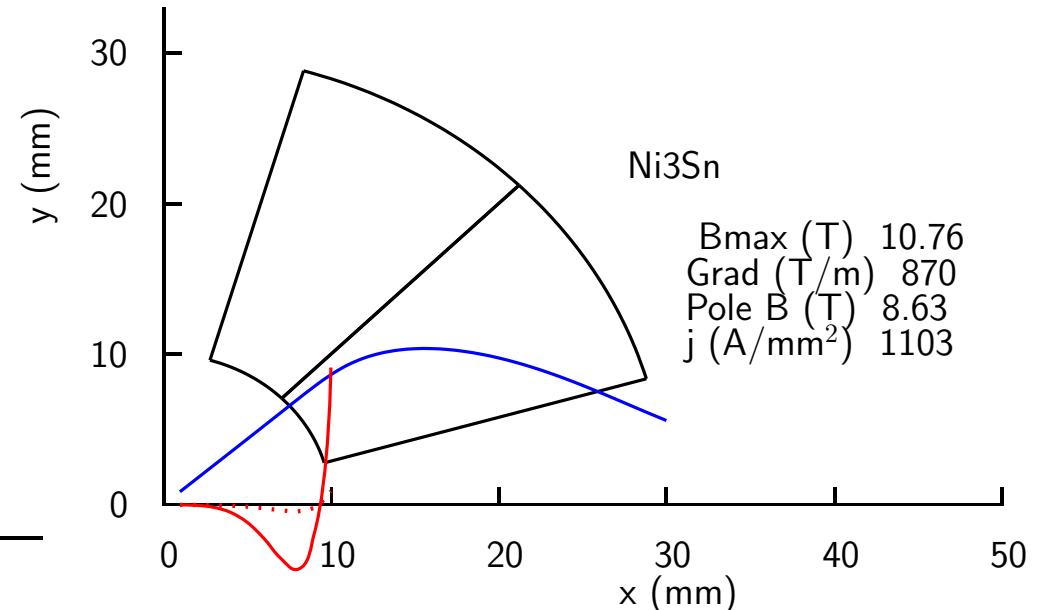
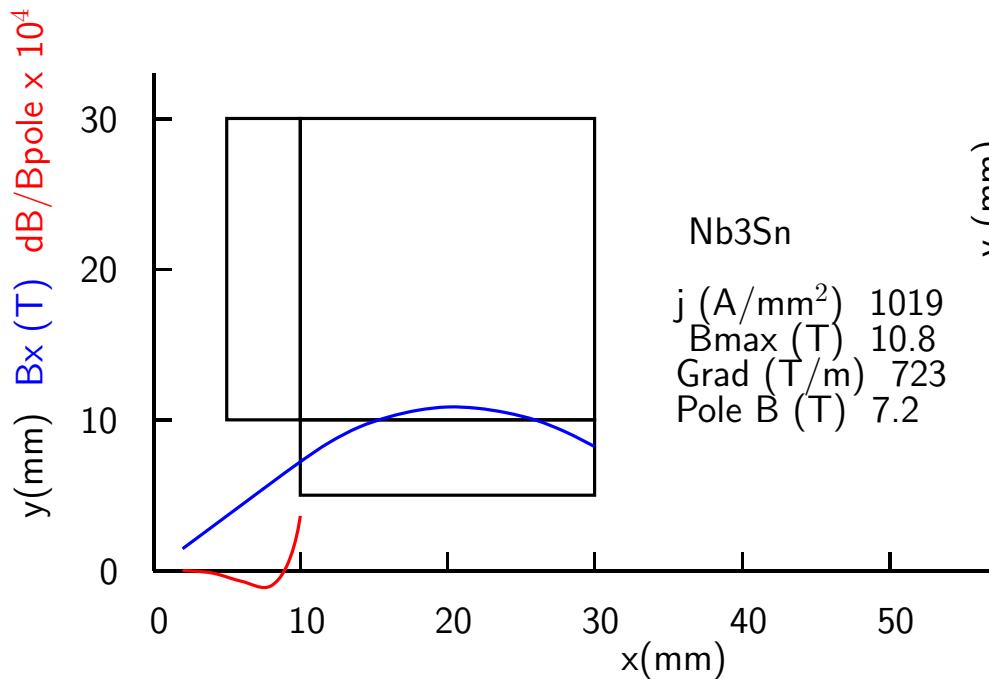


B_{pole} and Gradient vs. R

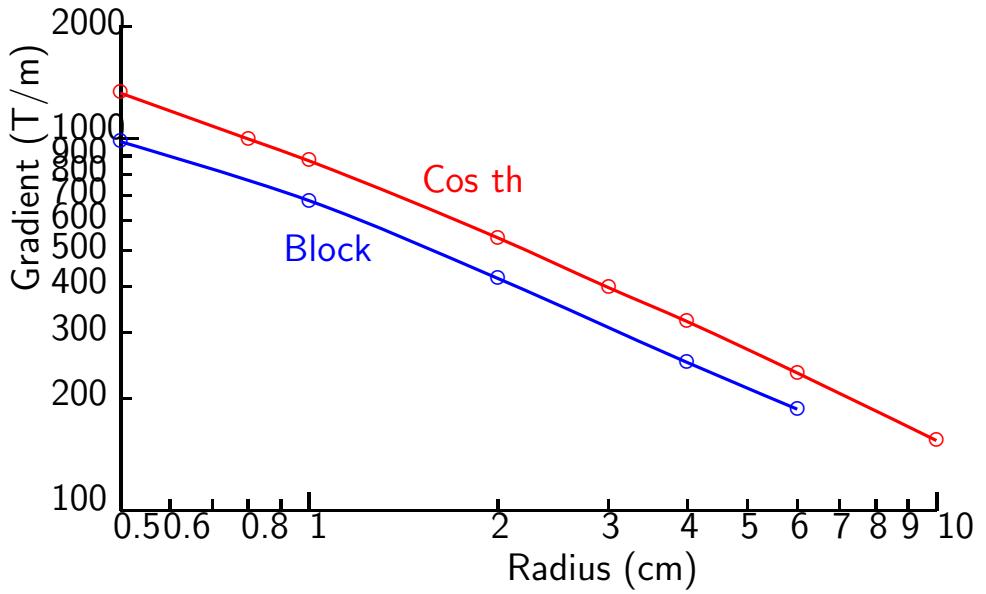


- Huge gains if radius reduced

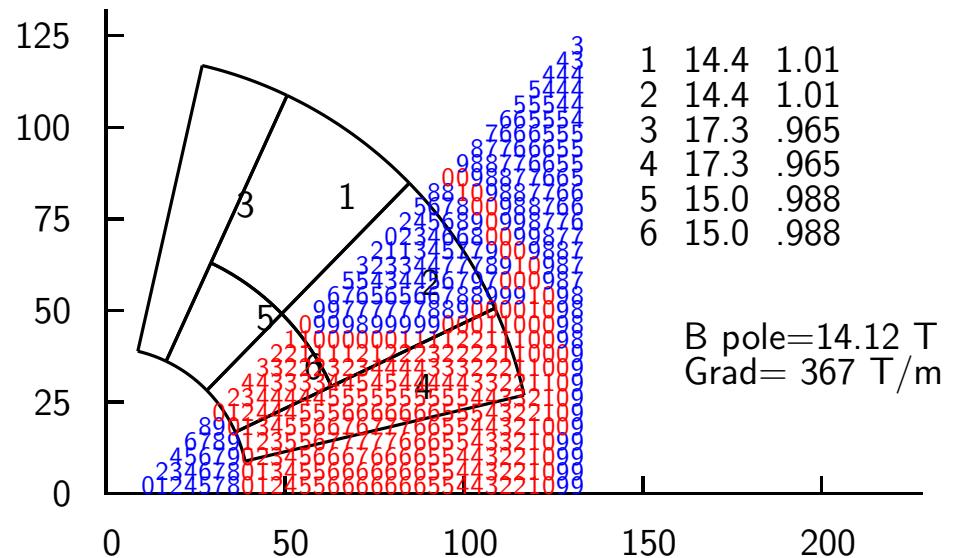
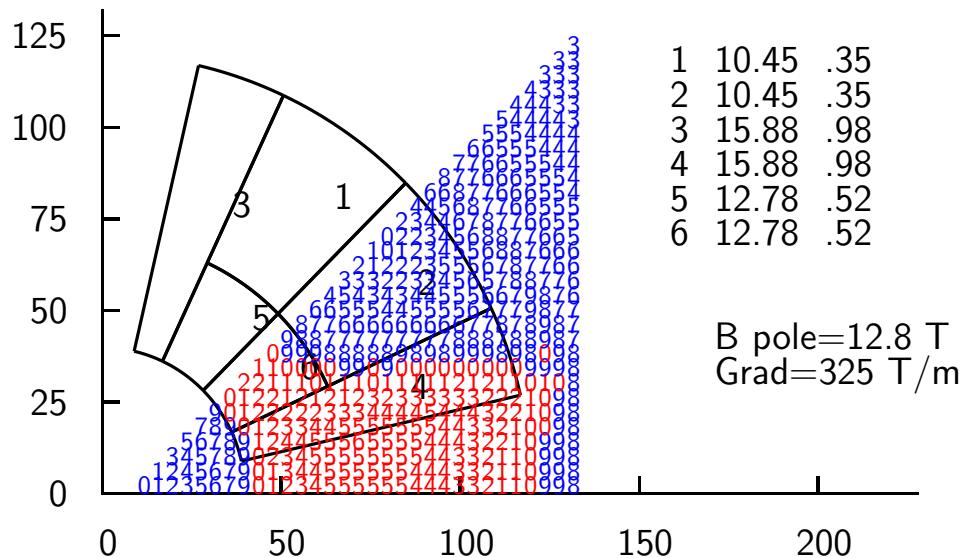
Aside: "Block" Cross Section vs. Cos θ



- Blocks shape easier to wind, but
- 20% loss of gradient using L shape

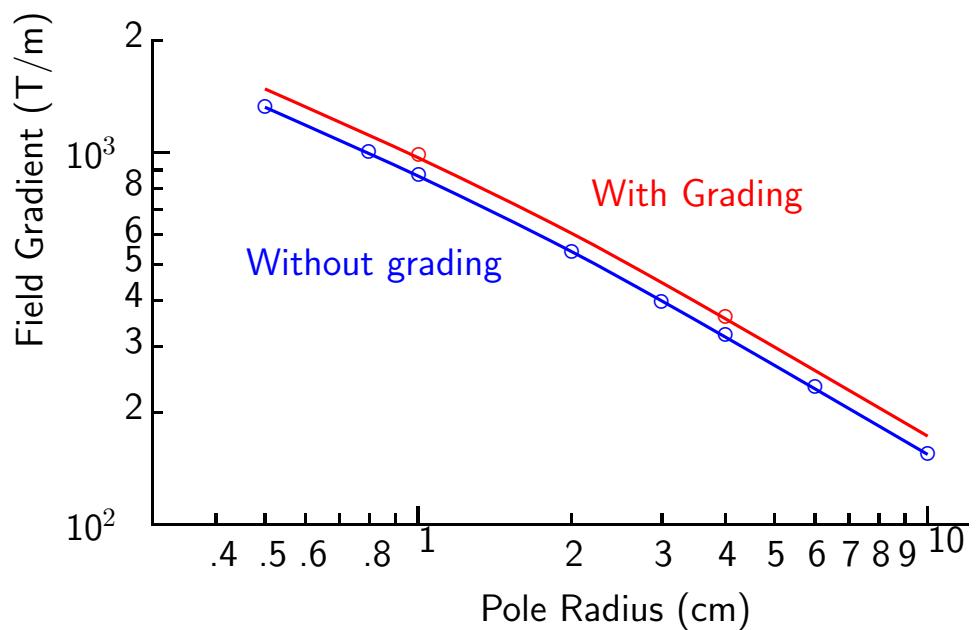
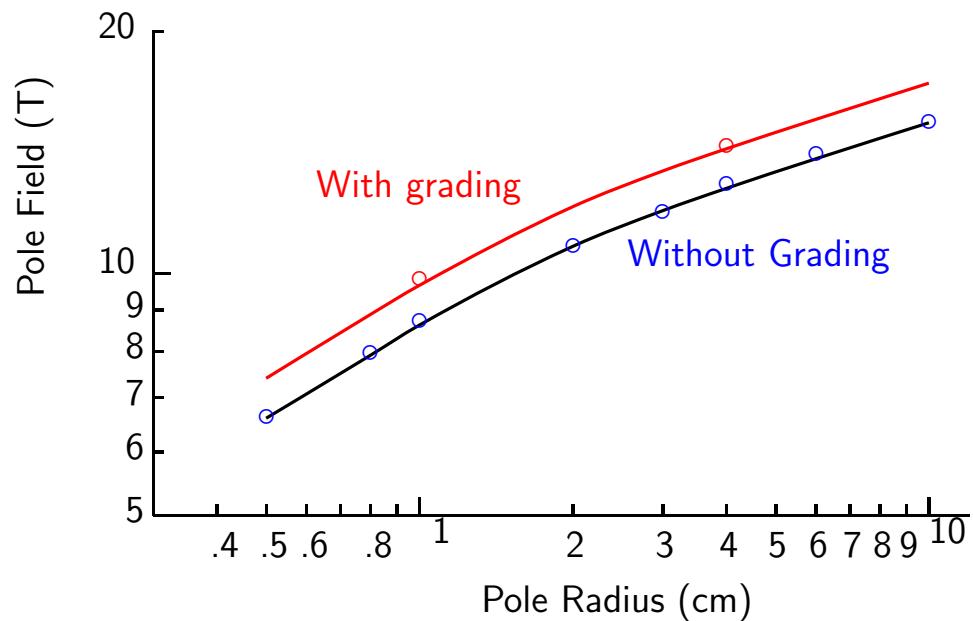


Grading super-conductor current densities



- Tables show fraction of short sample currents by block
- Without 'grading' inner blocks run far below maximum
- Adjusting densities by choice of cable thickness brings all blocks to same level
- Field and gradient gain is 10 %
- Small further gain with more, or better, block choices

Fields vs radius with/without grading



- 10% gain appears independent of radius

Use of exotic materials for pole tips

Holmium

only becomes ferromagnetic below 20K and saturates at about 4 Tesla.

<http://en.wikipedia.org/wiki/Holmium>~~

<http://www.stanfordmaterials.com/ho.html>

Phys. Rev. 109 (1958) 1547

http://prola.aps.org/pdf/PR/v109/i5/p1547_1

Dysprosium

Becomes ferromagnetic below 85K and saturates at maybe 3.5 Tesla

Physica B211 (1995) 345 "Magnetically aligned polycrystalline dysprosium as ultimate saturation ferromagnet for high magnetic field polepieces"

[http://dx.doi.org/10.1016/0921-4526\(94\)01059-A](http://dx.doi.org/10.1016/0921-4526(94)01059-A)

Gadolinium

Saturates at 3.2 T at 80 deg K

<http://en.wikipedia.org/wiki/Gadolinium> \$130/kilogram

The Curie point is described as a phase transition.

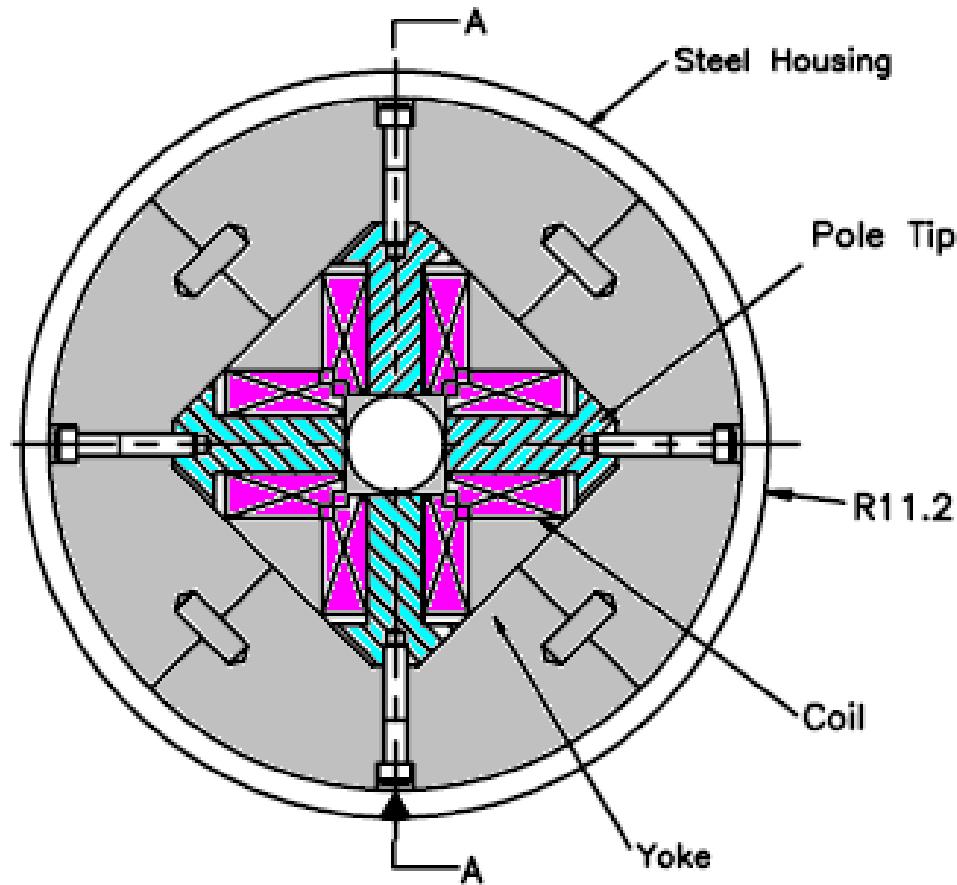
<http://en.wikipedia.org/wiki/Ferromagnetic>

Argonne super-conducting quad using Holmium

NIM A313 (1992) 311;

<http://accelconf.web.cern.ch/AccelConf/p95/ARTICLES/FAQ/FAQ09.pdf>

http://www.phy.anl.gov/accelerator_rd/publications/QUAD_PAC95.pdf

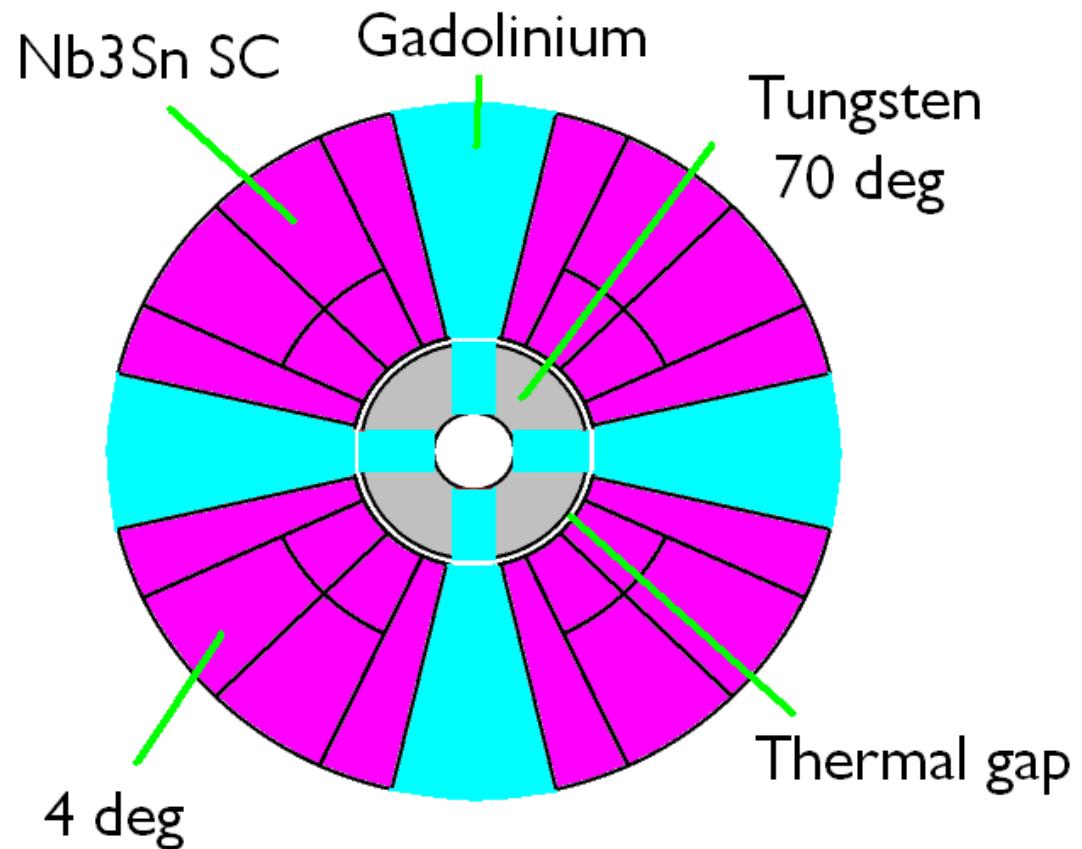


Rad=1.5 cm Bpole=5.25 T Grad-350 T/m

Use of Exotics for our use

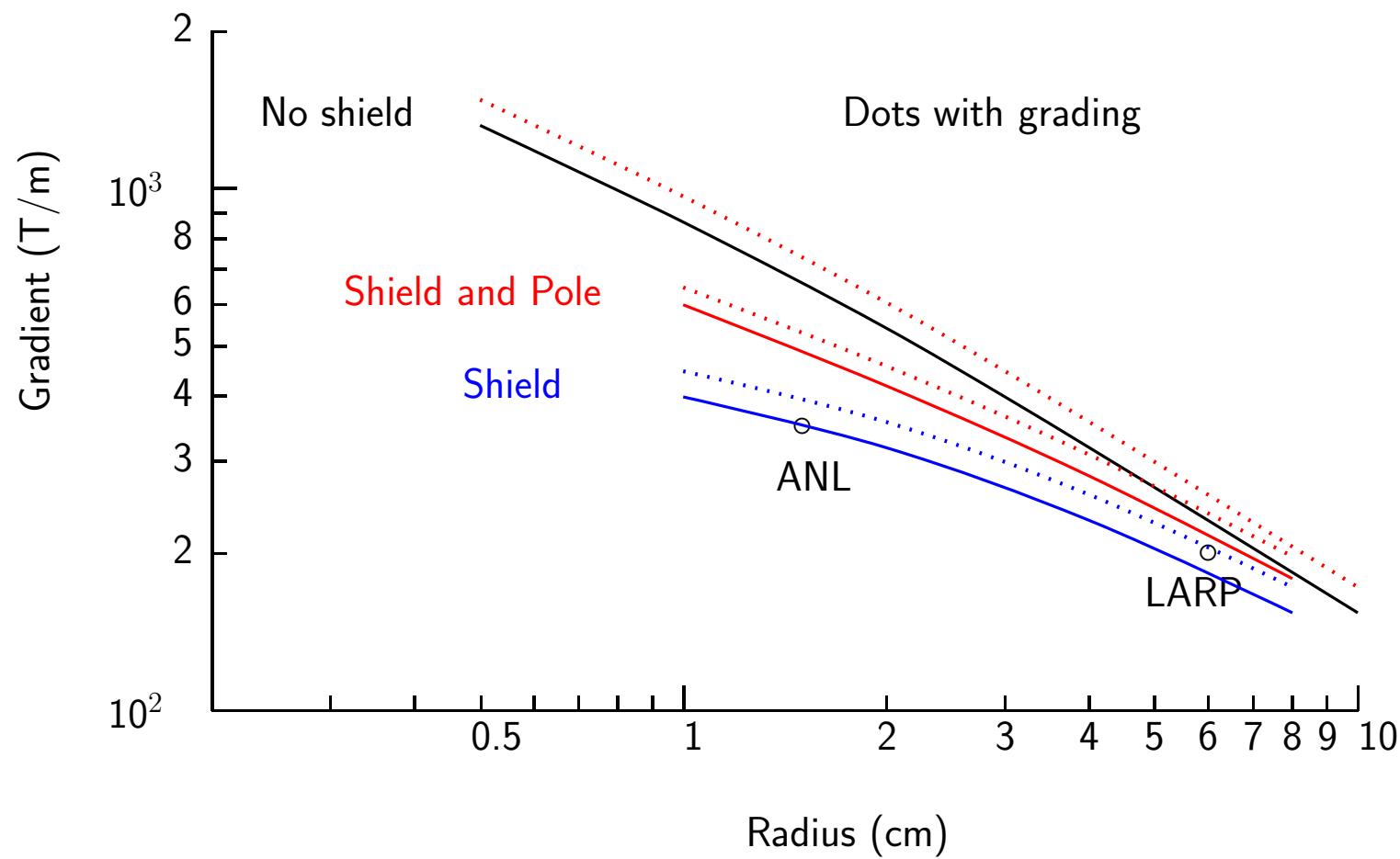
- Because of decay electron halo, we will need some shielding - assumed 2 cm
- Having ferromagnetic poles passing through this shielding would add significantly to the gradient
- The shielding, and poles, can not be at 4 deg for the heat load
- 70-80 degrees is probably ok
- That rules out Holmium, but leaves Gadolinium and Dysprosium as possibilities
- They saturate at 3.2-3.5 T and should add about 2 T to the pole tip field, in addition to that directly from the coils
- Since the final focus quads will be inside the detector solenoidal field, they will need bucking solenoids to shield them

Conceptual design

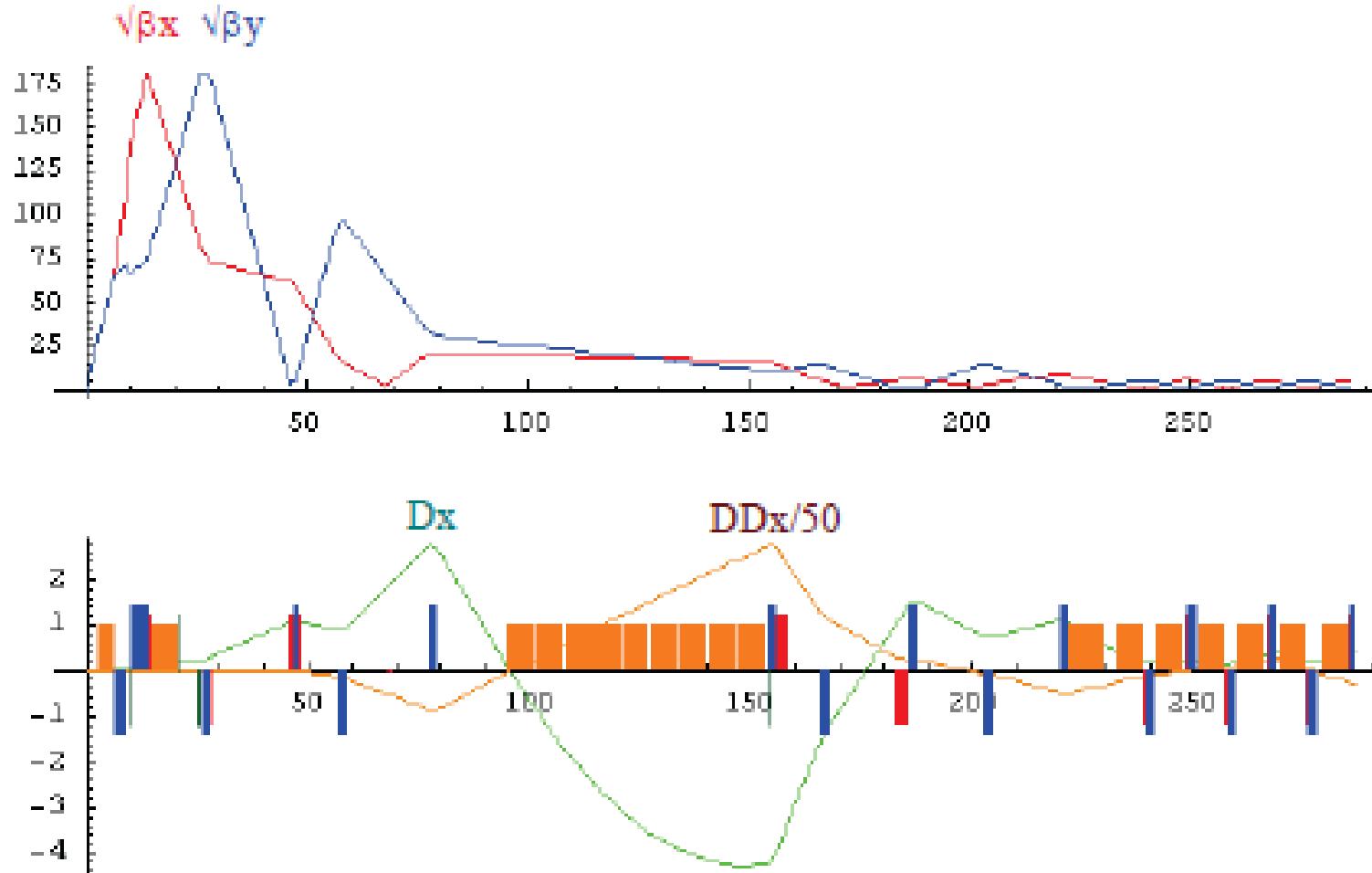


- The Gadolinium. or Dysprosium will be fully saturated along its length
- It will bring flux from the outer conductor to the pole face
- There will be a negligible effect on the field due to the nearer conductors: most of the direct field
- There will be an additional ≈ 2 T pole tip field from the ferromagnetic pole
- Support of pole material at 80 degrees k will be unstable and tricky

Gradients vs Rad

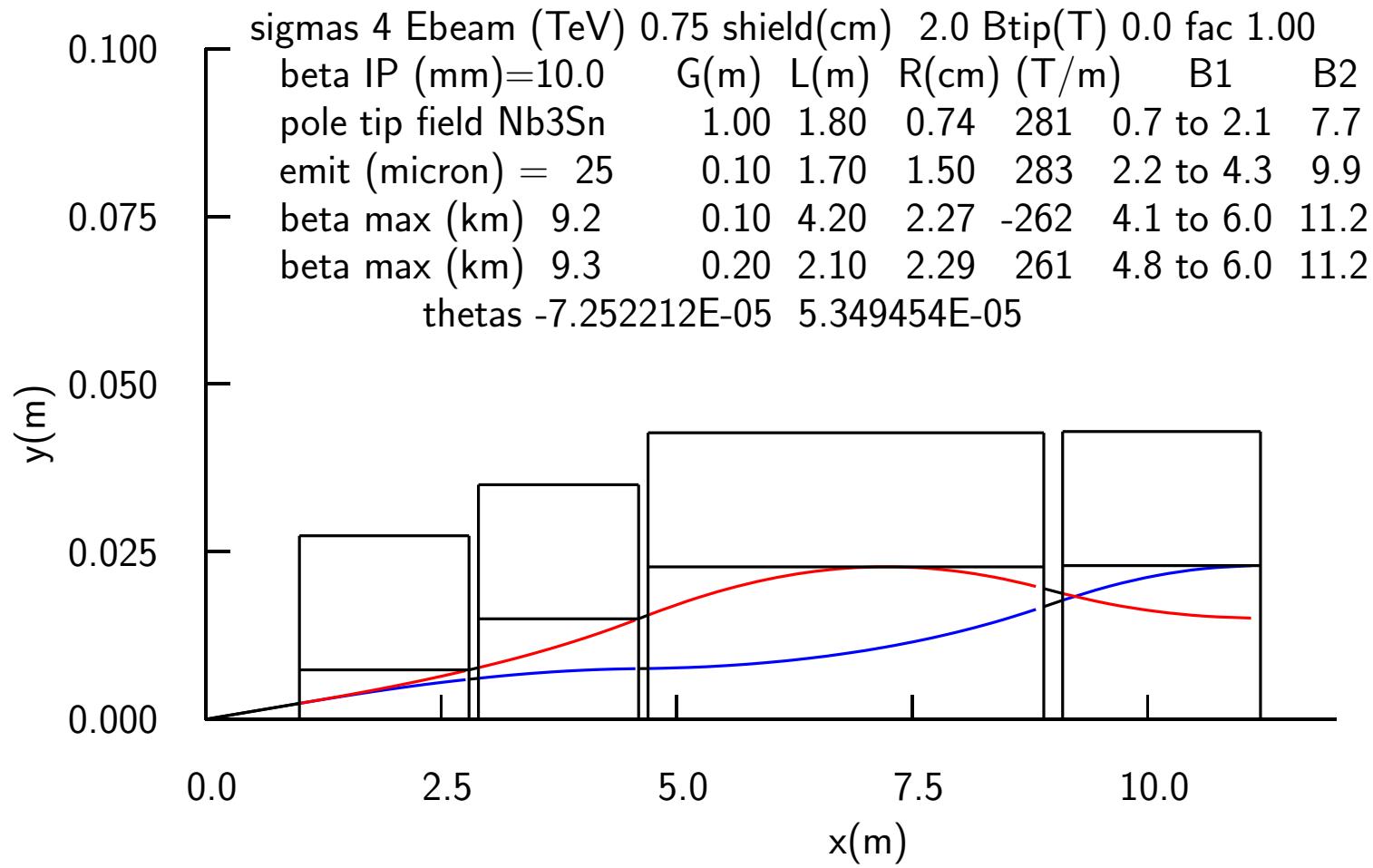


Collider Final focus design



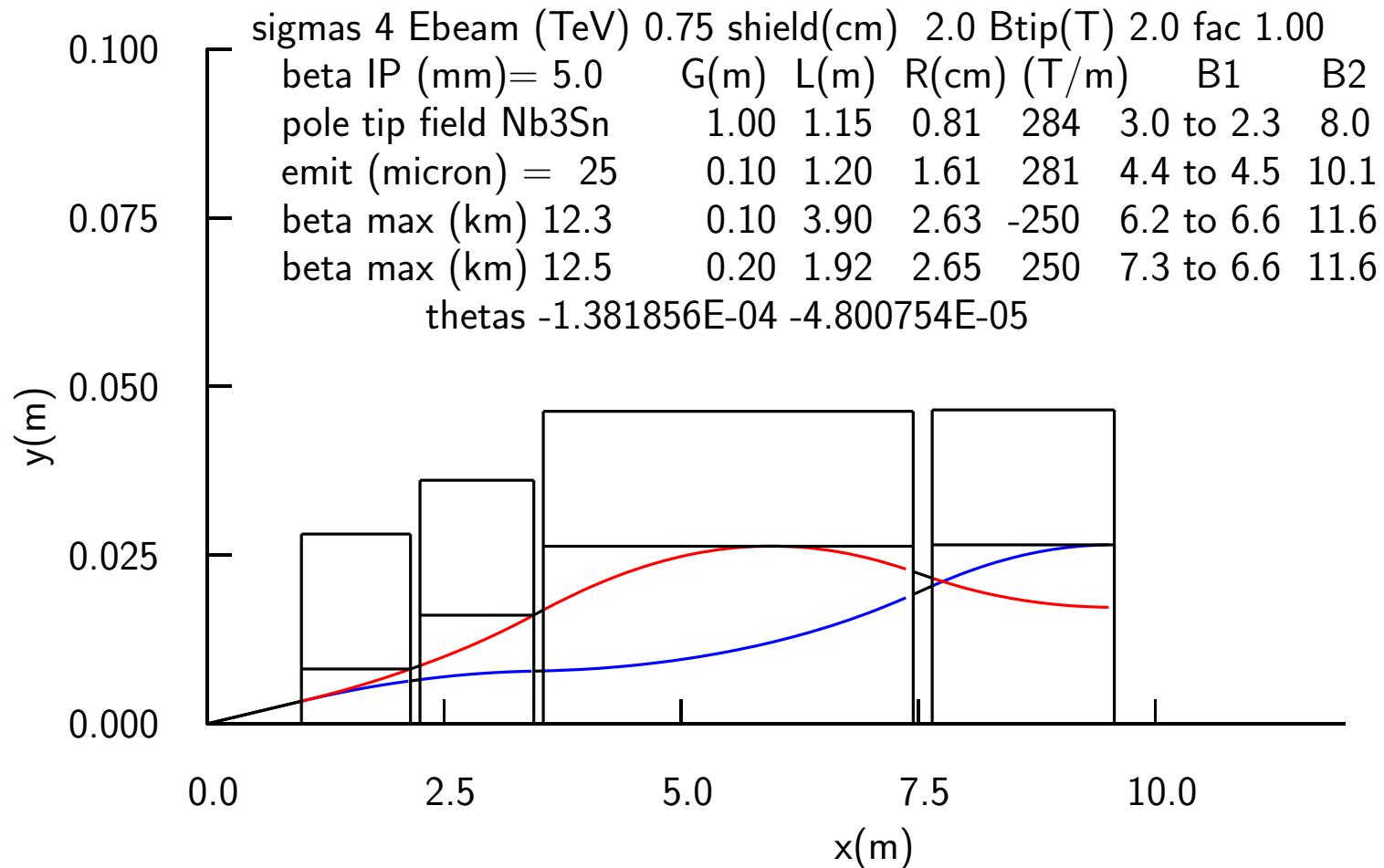
- Yuri and Eliana's Dipole First design
- $\beta_{max} = 175^2 \text{ m} \approx 30 \text{ km}$
- Aim to keep $\beta_{max} \leq 30 \text{ (km)}$, but with lower β^* for higher luminosity

Final focus with high grad quads, shield, $\beta^*=10$ mm



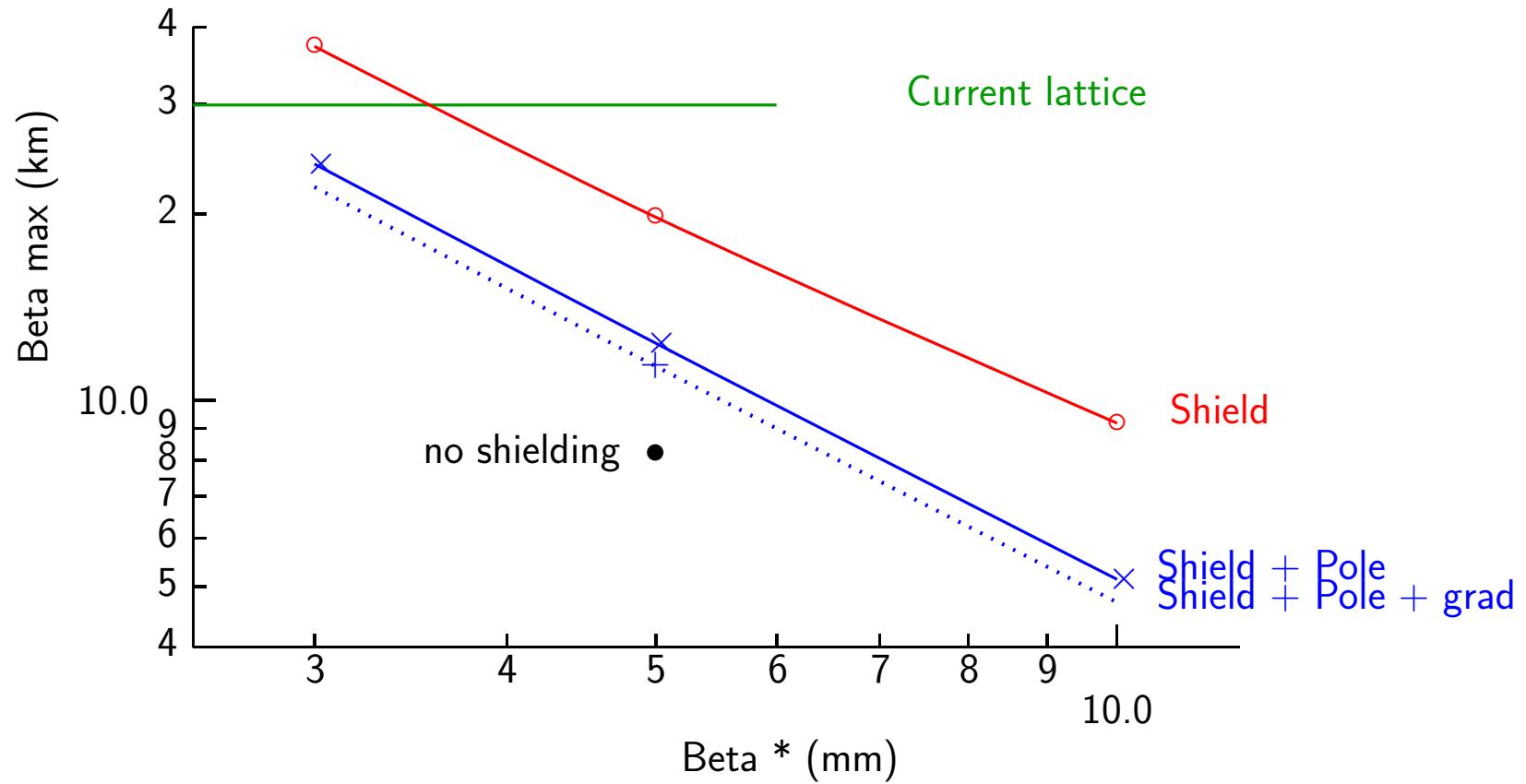
- For the same β^* : $\beta(max) \approx 1/3$ Yuri/Eliana's (9.2 vs. 30 km)

With 2 cm shielding, Exotic Pole, and $\beta^*=5$ mm



- $\beta(\max) \approx 1/3$ Yuri/Eliana's (12.2 vs. 30 km)
- Poles assumed to follow changing beam dimensions

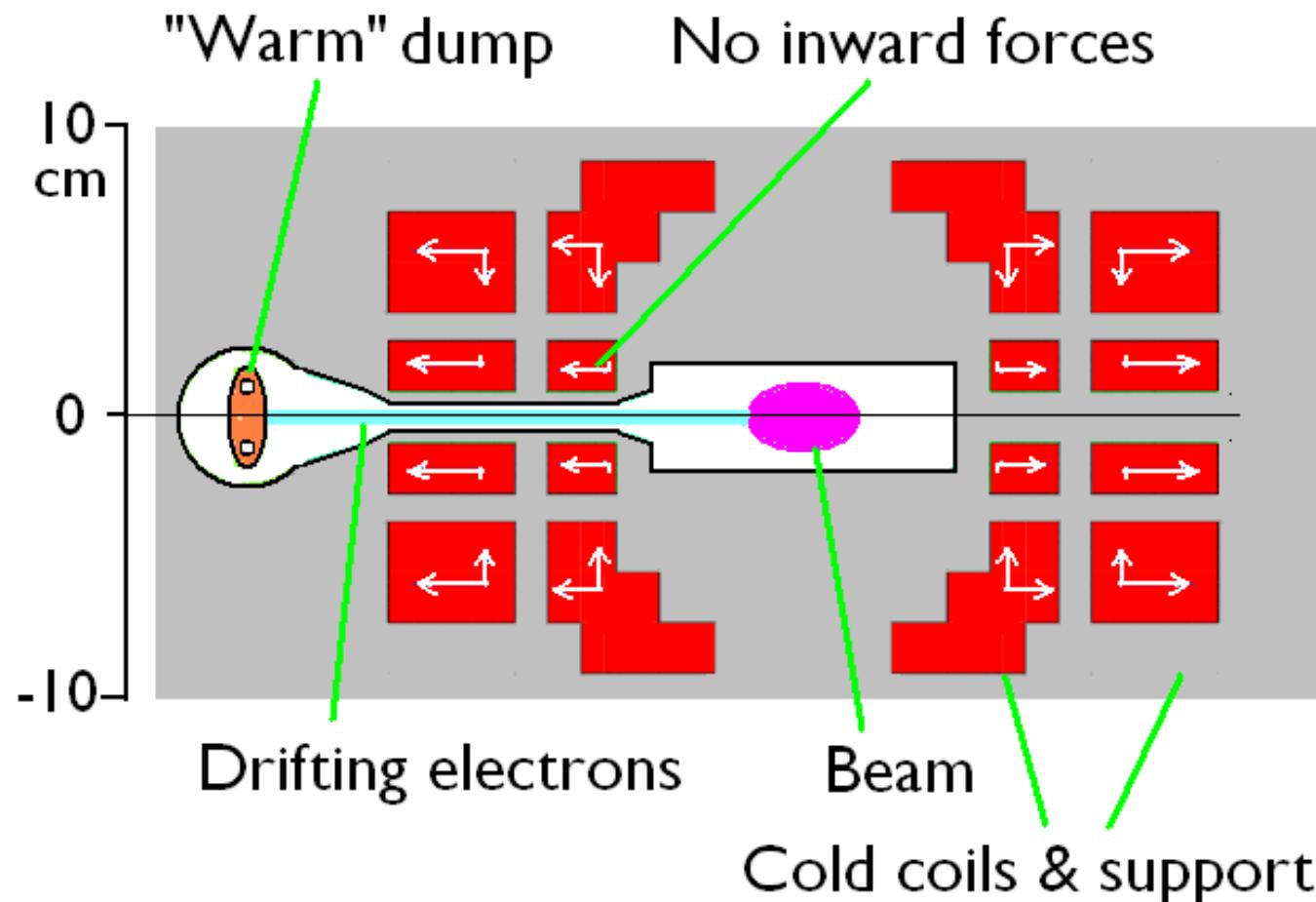
Beta max vs. Beta*



- With 2 cm shield: $\beta^* = 3.5 \text{ mm}$ vs. 10 mm for same $\beta_{\max} = 30 \text{ km}$
 $\beta^* = 5 \text{ mm}$ has $\beta_{\max} = 20 \text{ (km)}$
- With shield & pole: $\beta^* = 2.5 \text{ mm}$ vs. 10 mm for same $\beta_{\max} = 30 \text{ km}$
 $\beta^* = 5 \text{ mm}$ has $\beta_{\max} = 13 \text{ (km)}$
- Hopefully ok without dipole first (for which there is no room)

HTS/Nb₃Sn Open Mid-Plane Dipole (Gupta)

- HTS Dipoles should allow ave bending field ≈ 10 T
- It makes no sense to stay with LTSC dipoles
- 13 T design with Nb₃Sn 15 T with HTS



Possible New Parameters

	Current	Base	New Ideal	Compromise	
Luminosity	1.0	4.0	1.0		$10^{34} \text{ cm}^2 \text{sec}^{-1}$
Beam-beam Tune Shift	0.1	0.1	0.03		
Muons/bunch	2	2	1		10^{12}
Ring <bending field>	5.2	10.4	10.4		T
Beta at IP = σ_z	10	5	5		mm
rms momentum spread	0.1	0.2	0.1		%
Muon survival	0.07	0.07	0.05		
Repetition Rate	12	12	17		Hz
Proton Driver power	4	4	4		MW
Trans Emittance	25	25	35	pi mm mrad	
Final solenoids	50	50	40	T	
Long Emittance	72,000	72,000	36,000	pi mm mrad	
6D Emittance	45	45	45	$10^{-12} (\text{m rad})^3$	

- 6 D emittance the same
- Reduced transmission (5% vs. 7%)
- 15 T open mid-plane dipoles (Gupta)
- Cooling in 40 T solenoids to $35 \mu\text{m}$
- 5 mm beta* using high grad quads
- Fewer Muons per bunch (1 vs 2 10^{12})
- 0.2 % rms mom spread
- Same momentum spread (0.1 % rms)

Conclusion

- 200 T/m Nb₃Sn Quad under construction by LARP
- Using this material: Gradients much higher than assumed now
- Need for tungsten shields lowers gradients
- Grading the sc gives relatively small gain
- Exotic magnetic materials gives large gain
- Use of such quads could lower β^* in collider ring
- Also reasonable to use 15 T HTS open mid-plane dipoles in ring
- Allows either
 1. Four times luminosity, or
 2. Easier parameters for same luminosity (Chuck)
- To Do
 - Magnet simulations using code like OPERA for magnet material saturation
 - MARS study of needed shielding
 - Plasma (for μ^-) and e beam (for μ^+) focusing